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CORRO[illegible] OF METALS IN COAL ASH: A FIELD STUDY

Report No 84-390-K

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ABSTRACT

This report contains the results of a two-year field study of the corrosion of metals in fly ash and bottom ash. Metal specimens were embedded in the test media, compacted in containers installed in an open field. The corrosion rates of the metals in the ash were measured after one- and two-year periods and were compared with the corrosion of the same metals in a Class 'A' backfill. The environmental factors affecting the metal corrosion in the ash were also studied. The practical implication of the data on the use of coal ash as backfill is discussed.

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EXECUTIVE SUMMARY

CORROSION OF METALS IN COAL ASH: A FIELD STUDY

A.C. Headon and H.T. Chan
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This is a report of a two-year field study of the corrosion of metals in fly ash and bottom ash. These studies are a continuation of the laboratory corrosion studies of metals in coal ash previously reported (Research Division Report No 82-435-K).

Metal specimens were embedded in the test media and compacted in containers installed in an open field. The corrosion rates of the metals in the ash were measured after one- and two-year periods and were compared with the corrosion of the same metals in a Class 'A' backfill.

The percent degree of saturation and temperature depended on the climatic conditions at the test site. The laboratory studies were conducted at controlled percent degrees of saturation and at a constant temperature.

The average corrosion rates for the five metals tested in fly ash and bottom ash from Lakeview Thermal Generating Station are low and compare favourably with the average corrosion rates of the same metals in granular 'A' exposed at the same site.

Pitting, however, was somewhat more extensive and of a greater depth for carbon steel in fly ash and bottom ash. The exposure of the black zinc-iron alloy layer on the hot dip galvanized specimens within two years in fly ash and bottom ash and the micro pitting of copper in bottom ash did not occur in the granular 'A' material.

Particular attention will be given to the above differences when the final specimens are removed after five years total exposure.

The environmental factors, affecting the metal corrosion in the ash were also studied. The practical implication of the data on the use of coal ash as backfill is discussed.

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CORROSION OF METALS IN COAL ASH: A FIELD STUDY

1.0 INTRODUCTION

Coal ash is a valuable backfill material. However, its use could pose a concern regarding the potential corrosivity of the fly ash and bottom ash on metals which are sometimes used for buried services. To address this specific problem, a laboratory study was initiated in 1980 to evaluate the extent of corrosion of metals in coal ash.

This field corrosion study of metals in coal ash is a continuation of the laboratory corrosion studies of metals in coal ash/1/. The laboratory weight loss corrosion studies were conducted with a degree of saturation of the test media of either 100, 75 or 50%[1] for a period of six to seven months at a constant room temperature. The field corrosion, weight loss studies were conducted at a percent degree of saturation and temperature dependent on the climatic conditions at the test site.

Field specimens were removed after one and two years exposure time with a third set of specimens left for a five year exposure period.

This is the report of the results of the field test program after the two-year period.

---

1 50% degree of saturation means, 50% of the volume of the voids in the test medium is occupied by water.

2.0 EXPERIMENTAL PROGRAM

To substantiate the initial conclusions reported in the previous laboratory study, longer-term weight loss experiments under monitored field conditions were started in December 1981. The same metals, carbon steel, zinc coated steel, aluminum, copper and stainless steel were tested except that electro zinc coated steel was replaced with galvanized steel and the specimens were larger in size (Table I). Triplicate specimens were buried in fly ash, bottom ash and granular 'A' material to be removed after one year, two years and five years.

The test media were contained in reinforced sonotubes (cardboard paper tubes) 1.2 m (4 ft) in diameter and 1.7 m (5.5 ft) in height. The temperature and moisture content of the three media were monitored during the test period. The interstitial water of the fly ash medium was analysed after the first year's exposure.

The media were compacted with a wooden tamper in 15 cm (6 in) layers to a depth of 0.6 m (2 ft) from the lower end of the sonotubes before the placement of the specimens. The rest of the media were then compacted similarly on top of the metal specimens until the sonotubes were filled. Table 2 summarizes the characteristics of the test media.

Figure 1 and Photograph 1 show the location and orientation of the corrosion specimens in a sonotube before backfilling. Figure 2 and Photograph 2 show the location and orientation of the sonotubes after backfilling. Figure 3 gives a vertical cross-sectional view of a sonotube after backfilling.

Table 3 gives the analysis of the fly ash, bottom ash and granular 'A' material using the laboratory "shake" test. The fly ash and bottom ash were from Lakeview Thermal Generating Station. The granular 'A' material was from a gravel pit near Toronto.

3.0 EXPERIMENTAL RESULTS

The preparation, cleaning, and evaluation of the test specimens were conducted following the American Society for Testing and Materials Standard G1-81/3/.

Table 4 gives the average corrosion rate of the specimens in millimetres per year for the specimens removed after one year's exposure and the specimens removed after two year's exposure.

The corrosion rate of each metal in each media is the average of the corrosion rate of the individual metals of the triplicate sets. The use of corrosion rate implies that all mass loss has been due to general corrosion and not to localized corrosion such as pitting.

Photographs 3, 4, 5, 6, 7 and 8 show the typical type of corrosion found in the fly ash, bottom ash and granular 'A' material respectively after 1 and 2 year's exposure.

Table 5 gives a description of the type of corrosion that has occurred on the specimens that have been exposed for a two year period. This description for each metal is a composite of the corrosion characteristics of the three specimens exposed for each metal.

The description of the corrosion morphology in Table 5 indicates that the mass loss in some cases was due to localized corrosion, mainly in the form of pitting. Tables 4 and 5 must be considered together in estimating the importance of the corrosion for a particular application. Table 6 giving the average corrosion rates of steel, copper and zinc in a variety of soils is included as a comparison/4/.

4.0 THE CORROSION RATES OBSERVED IN THE FIELD TESTS

All the metals in all the media, except carbon steel in fly ash and bottom ash after one year's exposure, exhibit what would be considered a low corrosion rate based on the following criteria:

Corrosion Rates/5/

<0.03 mm/y	Low
0.03 - 0.13 mm/y	Moderate
0.13 - 0.25 mm/y	Severe
>0.25 mm/y	Very severe

The use of these criteria requires considerable judgement on the part of the user and must be tempered by economic and safety requirements. For example, a short-lived relatively low-cost project can normally tolerate a higher corrosion rate than a long-term, high investment project. These average corrosion rates assume a uniform loss of metal which may or may not be true. The maximum pit depth measurements must be taken into account in determining the severity of the corrosion from an operational standpoint. Sheet piling for example would be little affected by isolated pitting but a thin walled product carrying pipeline could be perforated with the subsequent loss of valuable product.

5.0 COMPARISON OF THE MEASURED CORROSION RATES WITH THE PHYSICOCHEMICAL CHARACTERISTICS OF THE MEDIA

In the previous Laboratory Corrosion Studies of Metals in Coal Ash/1/, the degree of saturation was controlled at 100%, 75% and 50% and the temperature was maintained at approximately 20°C. In the field tests these parameters were not controlled, but depended on the climatic conditions at the test site.

Figure 5 shows the climatic conditions at the test site as average temperature per month and total monthly precipitation per month during the two year test period. The temperature of the fly ash and bottom ash at the level of the corrosion specimens is also shown. Table 7 gives the resistivity, pH, moisture content percent by weight and percent degree saturation at the level of the corrosion specimens.

The corrosion of metals in soils has received considerable attention over the years. Because of the very complex nature of the soil-water-air/metal system, it is difficult to correlate any single physicochemical characteristic of the soil with its corrosion potential.

By considering a number of these characteristics, it is possible to make some estimate of the potential for corrosion in the fly ash, bottom ash and granular 'A' material and to compare that estimate with the measured values.

5.1 Soil Resistivity

Soil resistivity is often considered a basic criterion for evaluating the corrosivity of soil, with a lower resistivity being considered an indication of greater corrosion aggressiveness as follows:

Specific Resistance of the Soil (ohm-cm)	up to 500	500-1000	1000-2000	2000 10,000	>10,000
Evaluation of Soil Aggressiveness	very high	high	not so high	medium	low

Based on soil resistivity criteria the fly ash in this field test would be rated between a high and not so high aggressiveness and the bottom ash and granular A as having a low aggressiveness (Table 7).

5.2 Moisture Content

Next to the electrical resistivity, the moisture content of the soil exerts the greatest effect in deciding the intensity of corrosion. It has been found/6/ that the maximum subsoil corrosion for iron occurs between 25% and 35% moisture content by weight. Below 25% and above 35% the rate of corrosion decreases. This range can vary somewhat with different metals.

In these field tests (Table 7 and Figure 4) the moisture content per cent of the media was above or below the range of maximum corrosion. The moisture content per cent of the fly ash increased because of its very poor drainage characteristics/7/, the bottom ash decreased and the granular 'A' stayed close to its original value.

The corrosion rate in the fly ash was reduced from the rate indicated by its resistivity because of the high moisture per cent content. The corrosion rate of the bottom ash and granular 'A' are reduced by the low moisture content per cent. This low moisture percent content is indicated by the high resistivity.

5.3 pH of the Media

Acid soils have pH values ranging from 3 to 6. Neutral soils have pH values from 6 to 7.5 and alkaline soils have pH values from 7.5 to 9.5. In these tests bottom ash is an acidic medium and the fly ash and granular 'A' are alkaline media (Tables 3 and 7).

Alkaline media can be beneficial to buried steel but on the other hand the corrosion of aluminum and the zinc of the galvanized steel can increase in the more alkaline media. As aluminum and zinc are amphoteric metals, the corrosion rate can also increase in an acid medium.

5.4 Salt Composition of the Media

In some cases, it has been possible to correlate the presence of large amounts of chloride and sulphate with increased soil corrosivity. As shown in Table 3 the chloride content was relatively low for all the media. The sulphate contents of the fly ash and bottom ash, however, were quite high. This high sulphate content could be the reason for the rather rapid loss of the zinc coating on the galvanized samples in the fly ash and bottom ash, and the micro pitting of the copper tubing in the acidic bottom ash.

It is of interest to compare the values of the constituents obtained by analysing the leachate from the A, B, C laboratory "shake" test for fly ash and from analysing the fly ash interstitial water collected in December 1982 when the one year samples were removed.

For most components there is a progressive rise in solution concentrations in the A, B, C laboratory "shake" test. The concentration in C of this sequence, however, may not be the maximum available. The values for Ca, Na, K, Cl, SO_4 and conductivity are all higher when obtained from the interstitial water collected after one year.

5.5 Temperature of the Media

In most chemical reactions, an increase in temperature is accompanied by an increase in reaction rate or a decrease in temperature with a decrease in reaction rate.

In the field tests the temperature of the media rose and fell in step with the yearly temperature cycle. In Figure 5, (average temperature per month versus the months of the year), it can be seen that the temperature of the media rose higher than the average monthly temperature, but did not drop as low as the minimum monthly temperature. The corrosion rate during the winter months would have been considerably lower than the corrosion rate during the summer months.

The climate, precipitation and temperature, are other variables that must be considered in comparing the expected corrosion rates of various sites.

6.0 COMPARISON OF THE LABORATORY AND FIELD TEST WEIGHT LOSS RESULTS

The corrosion rates reported in the previous laboratory weight loss study/1/ cannot be directly compared with the rates obtained in this study because of the different conditions of the tests, such as per cent moisture content, temperature, conditions of the initial samples and period of exposure.

If a comparison is to be made, the fly ash one year field exposure results should be compared with the six month 100% degree of saturation results. The bottom ash and granular 'A', one year field exposure results should be compared with the six month 50% degree of saturation laboratory results.

When the above comparison is made it is found that although the corrosion rates obtained from the six months laboratory tests and the corrosion rates obtained from the one year field tests are not always numerically close, they both indicate a low to moderate corrosion rate for the metals. The six months laboratory tests also indicate the type of corrosion that has been found in the one year field tests. However, in order to confidently predict the long term corrosion rates and the long term morphology of the corrosion, this initial series of long term field testing is necessary.

The polarization resistance technique also indicates low to moderate corrosion rates, but a more sophisticated technique/8/ should be used to eliminate the errors inherent in this method.

7.0 CONCLUSIONS

The average corrosion rates for the five metals tested in fly ash and bottom ash from Lakeview Thermal Generating Station are low and compare favourably with the average corrosion rates of the same metals in granular 'A' exposed at the same site.

Pitting, however, was somewhat more extensive and of a greater depth for carbon steel in fly ash and bottom ash. The exposure of the black zinc-iron alloy layer on the hot dip galvanized specimens within two years in fly ash and bottom ash and the micro pitting of copper in bottom ash did not occur in the granular 'A' material. Particular attention will be given to the above differences when the final specimens are removed after five years total exposure.

ACKNOWLEDGEMENTS

Mr. N.A. MacDonald, Mr. J.P. Adams, Mr. K.M. Hassan and Mr. M.I. Grills of the Civil Research Department assisted in this testing program and their contribution is acknowledged.

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TABLE 1

DESCRIPTION OF METAL TEST SPECIMENS

MATERIAL	APPROXIMATE DIMENSIONS IN CENTIMETRES	APPROXIMATE WEIGHT IN GRAMS
304 Stainless Steel Bar, Round, Centreless Ground	0.63 diam x 15	38
A36 Carbon Steel Bar, Flat Hot Rolled, Black	5 x 15 x 0.63	380
1100F Aluminum Plate	5 x 15 x 0.63	128
Hot Dip Galvanized A36 Carbon Steel Bar Zinc Coating Thickness 0.16 mm to 0.23 mm (6.5 mils to 9.0 mils)	5 x 15 x 0.63	395
Type M Copper Water Pipe	1.27 diam x 15	42

TABLE 2

DESCRIPTION OF TEST MEDIA

TEST MEDIA	PARTICLE SIZE	BULK DENSITY OF COMPACTED MATERIAL AT START OF EXPERIMENT
Granular 'A'	60%* Gravel** 32% Sand 8% Silt	2041.1 kg/m^3 (127.4 lbs/ft^3) @5.2% moisture
Fly Ash	16% Sand 58% Silt 26% Clay	1520.3 kg/m^3 (94.9 lbs/ft^3) @19.1% moisture
Bottom Ash	40% Gravel Size 55% Sand 5% Silt	1203.1 kg/m^3 (75.1 lbs/ft^3) @21.3% moisture

* % by weight
** Gravel >4.8 mm
Sand >0.064 mm
Silt >0.002 mm
Clay <0.002 mm

TABLE 3

CHEMICAL ANALYSIS OF LEACHATE OF FLY ASH, BOTTOM ASH AND GRANULAR 'A' MATERIAL

QUANTITY ANALYSED	FLY ASH			FLY ASH INTERSTITIAL WATER	BOTTOM ASH			GRANULAR "A"		
	A*	B*	C*		A	B	C	A	B	C
Ca mg/L	400	625	630	537	66	158	266	9.2	13	17
Mg mg/L	4.9	11	17	8	3.5	8.9	18	3.1	5.9	9.7
Na mg/L	20	41	74	382	0.9	1.8	3.5	0.9	1.8	2.8
K mg/L	13	29	47	242	0.4	0.8	1.3	0.2	0.6	0.9
Cl mg/L	3.4	7.3	12.8	90	0.4	1.2	2.8	3.5	7.9	12.6
B mg/L	-	-	-	1.5	-	-	-	-	-	-
pH	9.3	9.0	8.9	9.6	4.0	3.9	4.0	9.3	9.1	8.7
SO_4 mg/L	999	1500	1560	2300	201	489	840	12	24	36
Conductivity mS/m	166	233	245	395	42	87	130	7.7	12.8	18.3
Total Alkalinity as $CaCO_3$ mg/L	56	86	122	81	-	-	-	18	21	28
Total Acid as $CaCO^3$ mg/L	-	-	-	-	51	116	139	-	-	-

* A,B,C laboratory "shake" test, methodology is outlined in Appendix/2/.

TABLE 4

AVERAGE CORROSION RATE OF SPECIMENS IN MILLIMETRES PER YEAR

ENVIRONMENT	CARBON STEEL	GALVANIZED STEEL	ALUMINUM 1100	1/2" TYPE M COPPER WATER PIPE	STAINLESS 304
Fly Ash					
1 yr exposure	0.035	0.017	0.0004	0.0002	Too small
2 yr exposure	0.018	0.018	0.0006	0.0001	to measure
Bottom Ash					
1 yr exposure	0.031	0.004	0.002	0.001	Too small
2 yr exposure	0.023	0.014	0.001	0.001	to measure
Granular 'A'					
1 yr exposure	0.021	0.003	0.0004	0.001	Too small
2 yr exposure	0.011	0.003	0.0004	0.001	to measure

TABLE 5

DESCRIPTION OF CORROSION AFTER TWO YEARS EXPOSURE

(A composite of three specimens)

ENVIRONMENT	CARBON STEEL	GALVANIZED STEEL	ALUMINUM 1100	1/2" (1.27 cm) COPPER WATER PIPE TYPE M	STAINLESS 304
Fly Ash	About 40% of the surface was corroded mainly in the form of pitting. The pits has a maximum diameter of 3.75 mm (0.15") with a maximum depth of 0.8 mm (0.03").	The corrosion was more severe on the lower face of the specimens. The black zinc-iron alloy layer was exposed on 50% of this face. 2% of the black zinc-iron alloy layer was exposed on the upper face. 0.05% bare base steel was exposed.	The specimens have corroded uniformly to a matte finish. This finish is a little less uniform on the lower face. Three micro-pits were found on one specimen.	Minor tarnishing of the surface.	No visible corrosion.
Bottom Ash	About 50% of the surface was corroded, mainly in the form of pitting. The pits had a maximum diameter of 1.6 mm (0.06") with a maximum depth of 0.5 mm (0.02")	The corrosion was more severe on the lower face of the specimens. The black zinc-iron alloy layer was exposed on 35% of this face. 0.1% of the black zinc-iron alloy layer was exposed on the upper face. No bare steel was exposed.	The corrosion occurs at isolated areas on a total of 5% of the surface. The corrosion is in the form of pitting or as etched areas containing pits. The largest pits are 1.6 mm (0.06" in diameter and 1 mm (0.04") in depth.	Overall micro-pitting of the surface.	No visible corrosion.
Granular 'A'	The corrosion was at isolated areas on about 15% of the surface of the specimen. There are pits within these areas up to 1 mm (0.04") diameter with a maximum depth of 0.25 mm (0.01").	No black zinc-iron alloy layer was exposed. Spangles (zinc crystals) are still visible. A grey coating has replaced the normal bright coating on 10% of the surface.	The corrosion occurs on a total of 3% of the surface as spots of slight tarnishing with blistering at a few locations. There are pits under the blistering. The largest pits are 1.5 mm (0.06") in diameter by 0.08 mm (0.03") deep.	Overall etching of the surface.	No visible corrosion.

TABLE 6/4/

CORROSION OF STEEL, COPPER AND ZINC IN SOILS

Average Corrosion Rates in mm/y (millimetres per year)

SOIL	STEEL 12 YEARS EXPOSURE	COPPER 8 YEARS EXPOSURE	ZINC 11 YEARS EXPOSURE
Average of Several Soils	0.02 (44 soils)	0.003 (29 soils)	0.015 (12 soils)
Tidal Marsh Elizabeth, N.J.	0.09	0.02	0.009
Montezuma Clay Adobe, San Diego California	0.07	0.003	-
Merrimac Gravelly ANSY Loam Norwood, Mass	0.004	0.008	-
Cinders	0.77 (2 years exposure)		

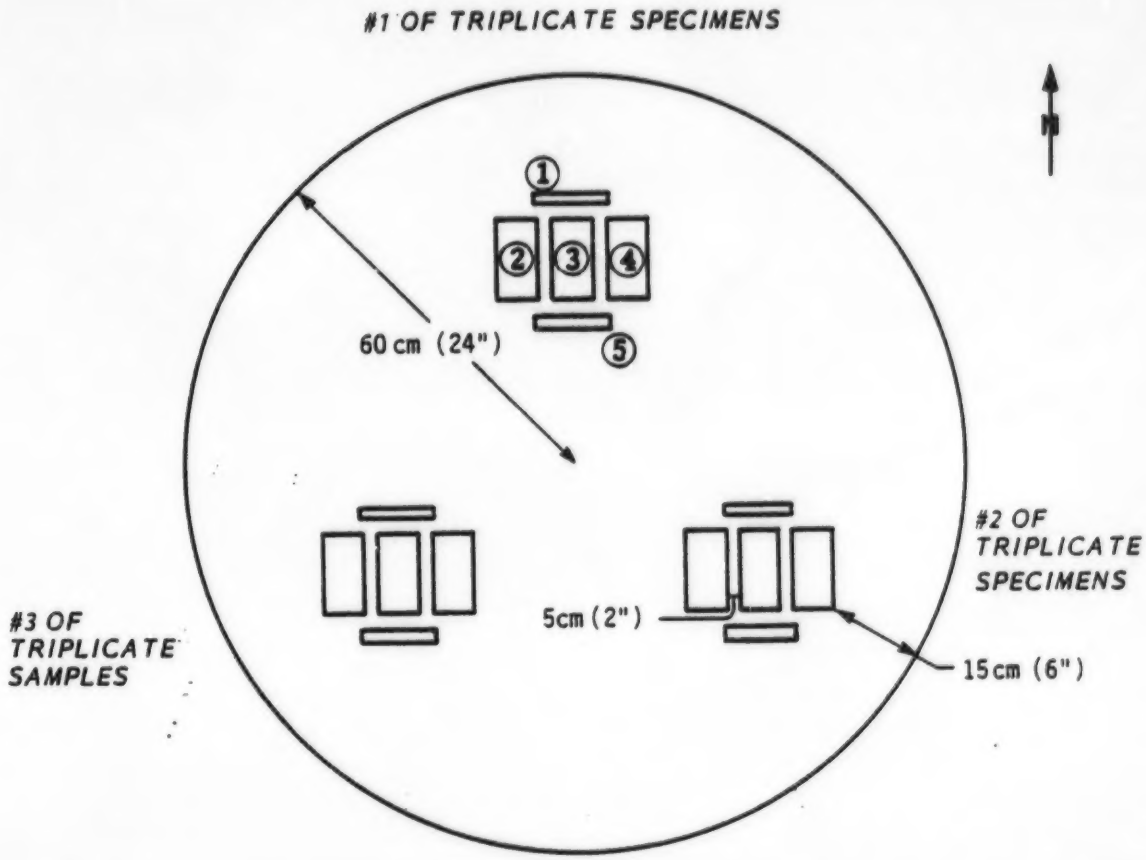
TABLE 7

CHARACTERISTICS OF THE ENVIRONMENT AT ONE AND TWO YEARS AT THE LEVEL OF THE SPECIMENS

ENVIRONMENT	RESISTIVITY Ω-cm	pH	MOISTURE CONTENT % BY WEIGHT*	% DEGREE SATURATION**
Fly Ash				
At 1 year	1080	7.5	50.5	83
At 2 years	900	9.4	50.5	82
Bottom Ash				
At 1 year	>30,000	5.5	9.3	35
At 2 years	>30,000	3.8	9.0	35
Granular 'A'				
At 1 year	>30,000	7.0	3.5	33
At 2 years	>30,000	8.1	3.5	33

* Moisture Content % by Weight = $\frac{\text{Weight of Water}}{\text{Weight of Dry Soil}} \times 100$

** % Degree Saturation = $\frac{\text{Volume Occupied by Water}}{\text{Total Void Volume}} \times 100$



LEGEND

① 304 Stainless Steel Bar, Round, 0.63cm Diameter, Centreless Ground

② A 36 Carbon Steel Bar, Flat, Hot Rolled, Black

③ 1100F Aluminum Plate

④ Galvanized A 36 Carbon Steel Bar

⑤ 12.7cm (1/2") Type M Copper Water Pipe

FIGURE 1

LOCATION AND ORIENTATION OF THE CORROSION SPECIMENS IN A SONOTUBE

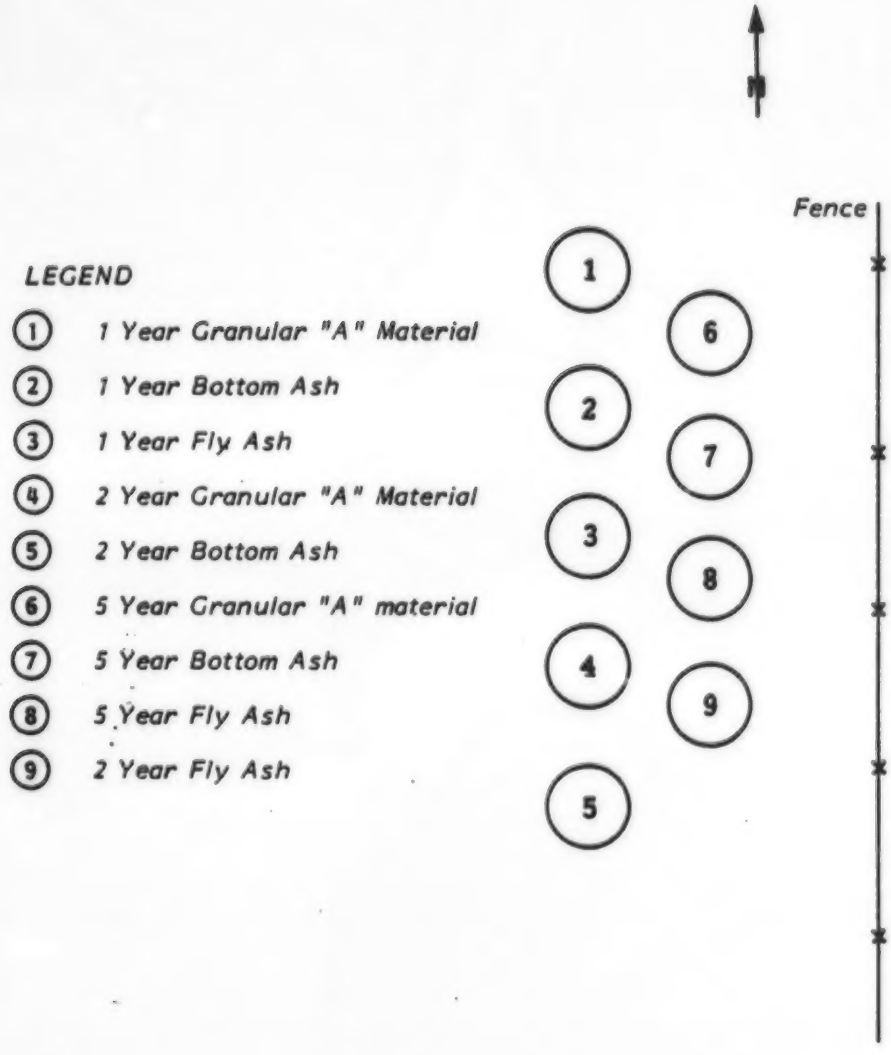


FIGURE 2

LOCATION AND ORIENTATION OF THE SONOTUBES

166919 RD

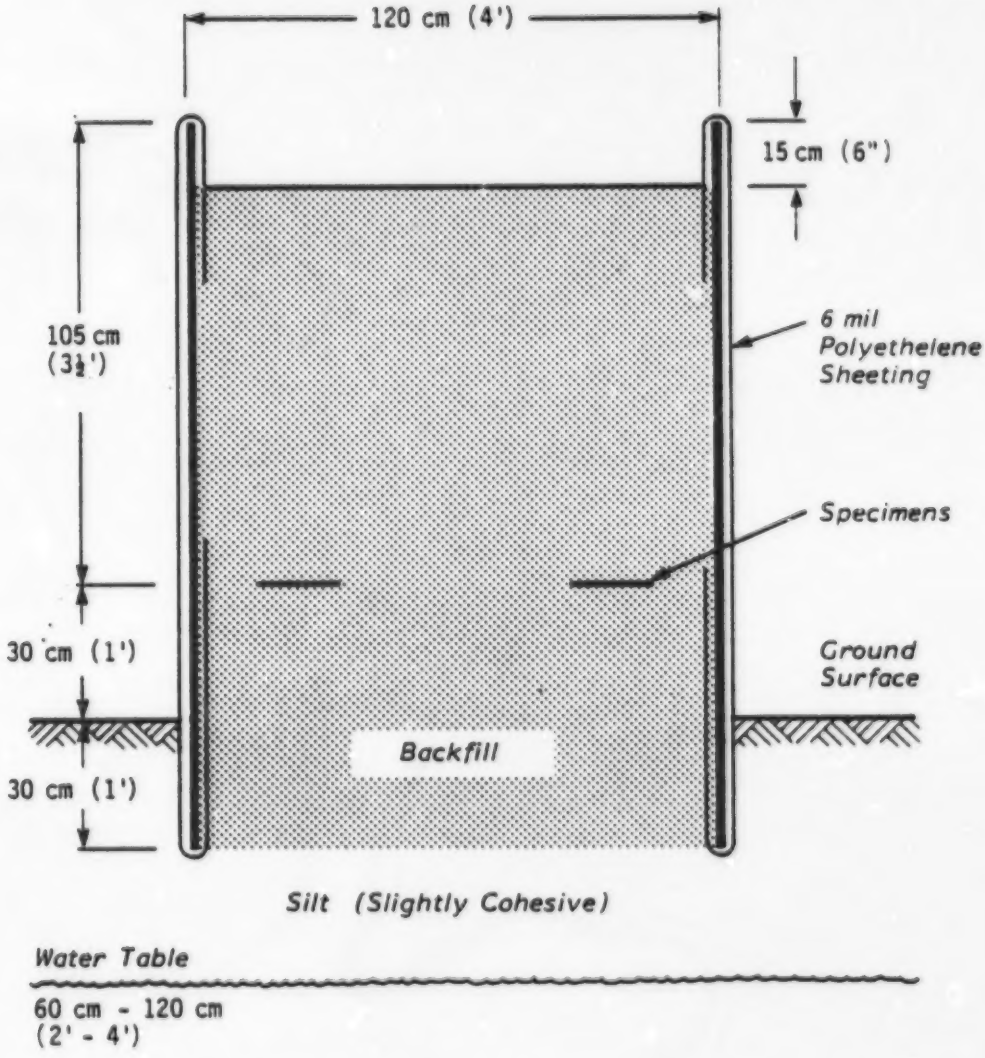


FIGURE 3

VERTICAL CROSS SECTIONAL VIEW OF A
SONOTUBE AFTER BACKFILLING

167087 RD

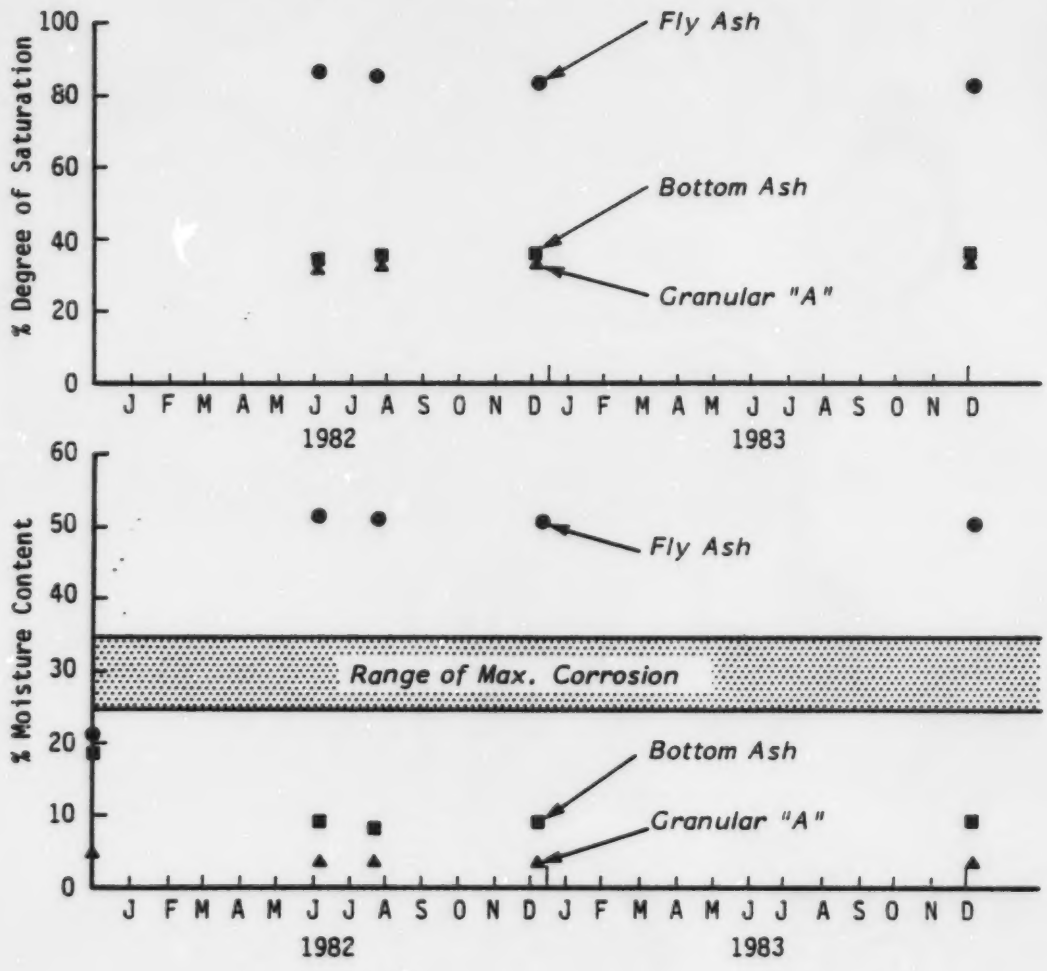


FIGURE 4

% DEGREE OF SATURATION & MOISTURE CONTENT% OF THE MEDIA DURING THE TEST PERIOD

167088 RD

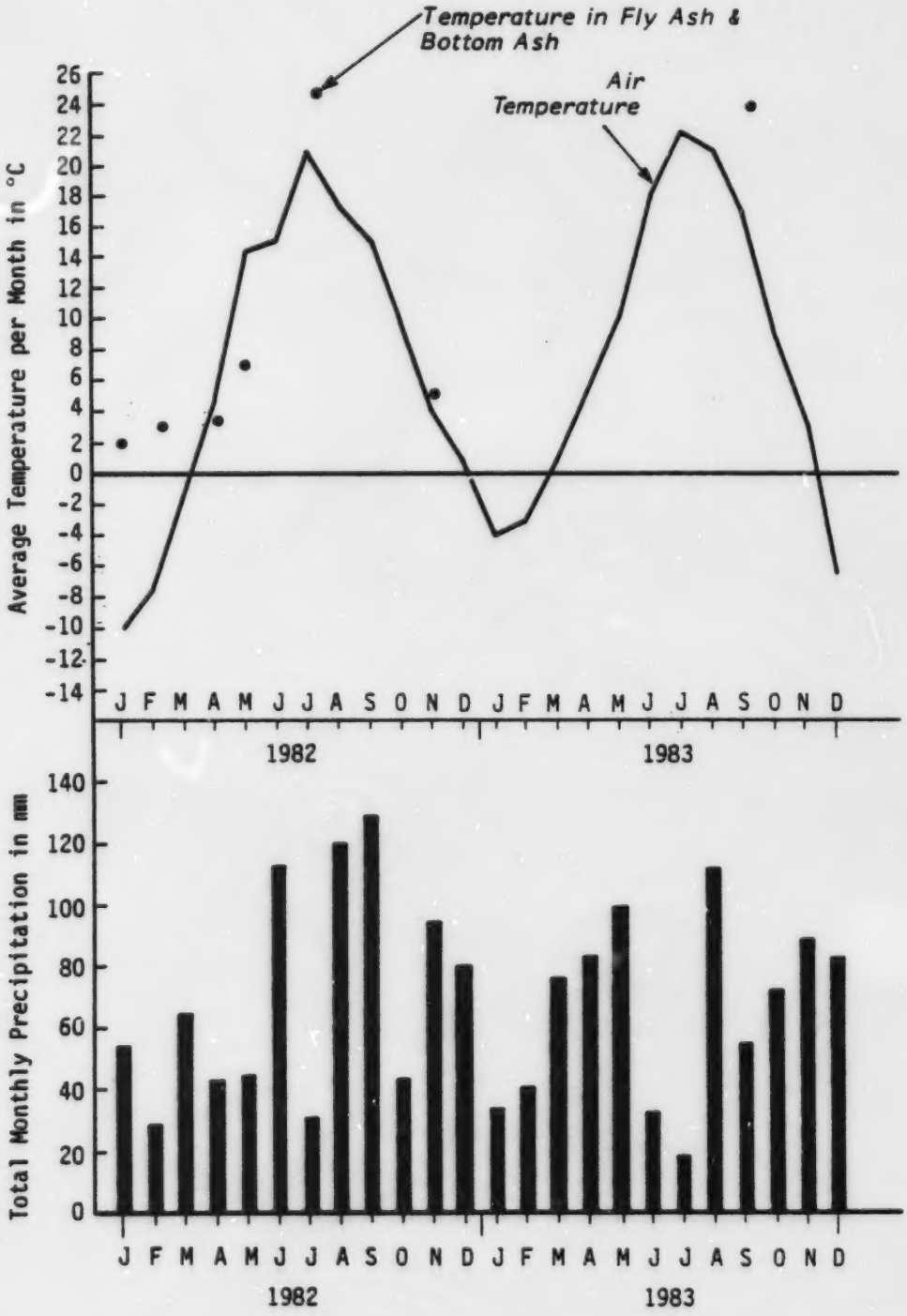


FIGURE 5

CLIMATIC CONDITIONS AT THE TEST SITE

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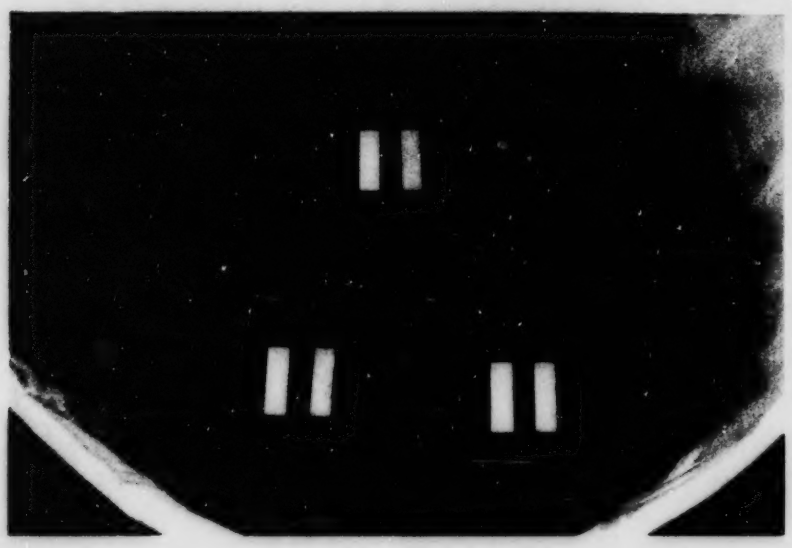


PHOTOGRAPH 1

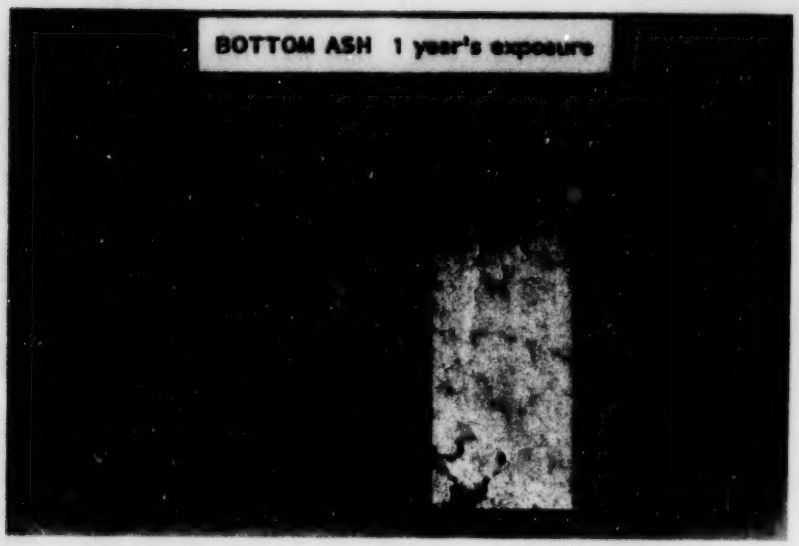
LOCATION AND ORIENTATION OF THE CORROSION SPECIMENS IN A SONOTUBE BEFORE BACKFILLING

PHOTOGRAPH 2

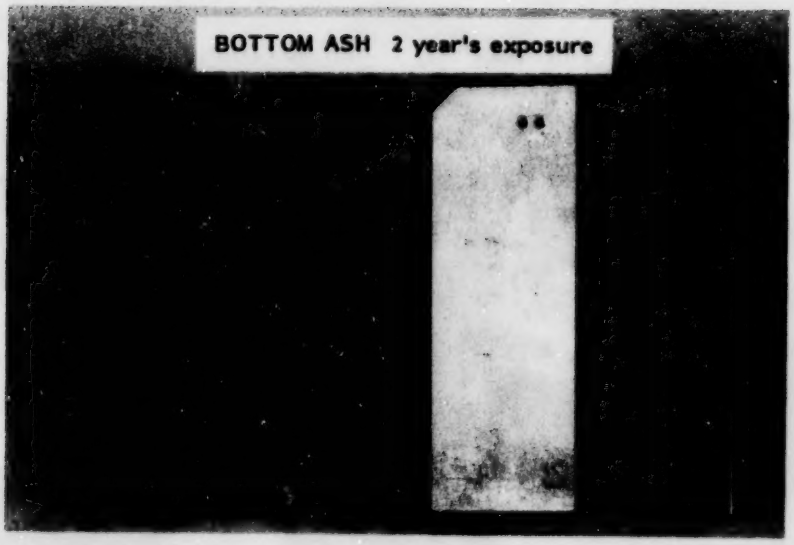
LOCATION AND ORIENTATION OF THE SONOTUBES AFTER BACKFILLING

PHOTOGRAPH 3

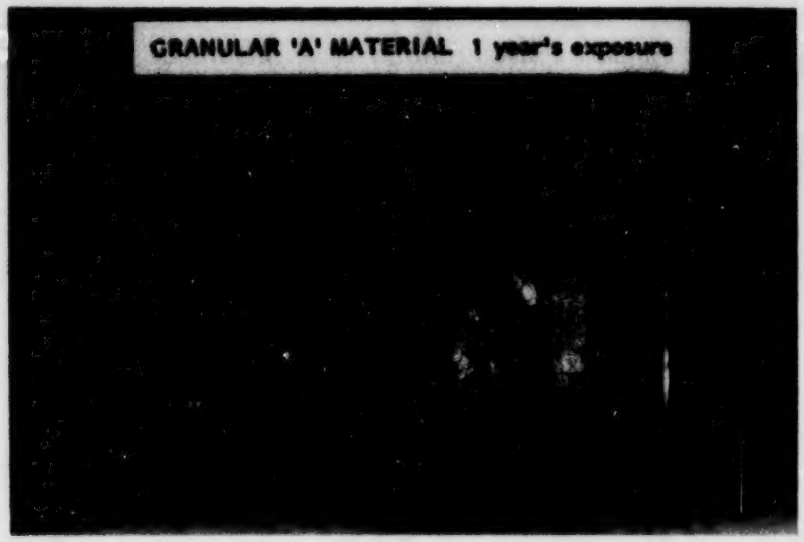
PHOTOGRAPH 4



PHOTOGRAPH 5



PHOTOGRAPH 6



PHOTOGRAPH 7

PHOTOGRAPH 8

APPENDIX

A, B, C SEQUENCE LEACHING TEST/2/

The letters A, B, and C denote the three stages of leaching, carried out for 24 h at each stage at an ash:water weight ratio of 1:10.

Stage A

Ash and deionized or distilled water are shaken in a standard shaker for 24 h. The solution is decanted and chemical measurements are made.

Stage B

Fresh ash at a ratio of 1:7.5 is added to the solution from Stage A and shaken for a further 24 h. The solution is decanted and chemical measurements are made.

Stage C

Fresh ash at a ratio of 1:5 is added to the solution from Stage B and shaken for a further 24 h. The solution is decanted and chemical measurements are made.

For most components there is a progressive rise in solution concentrations.